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Method of forming a circuit element on a surface

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Fig. 1

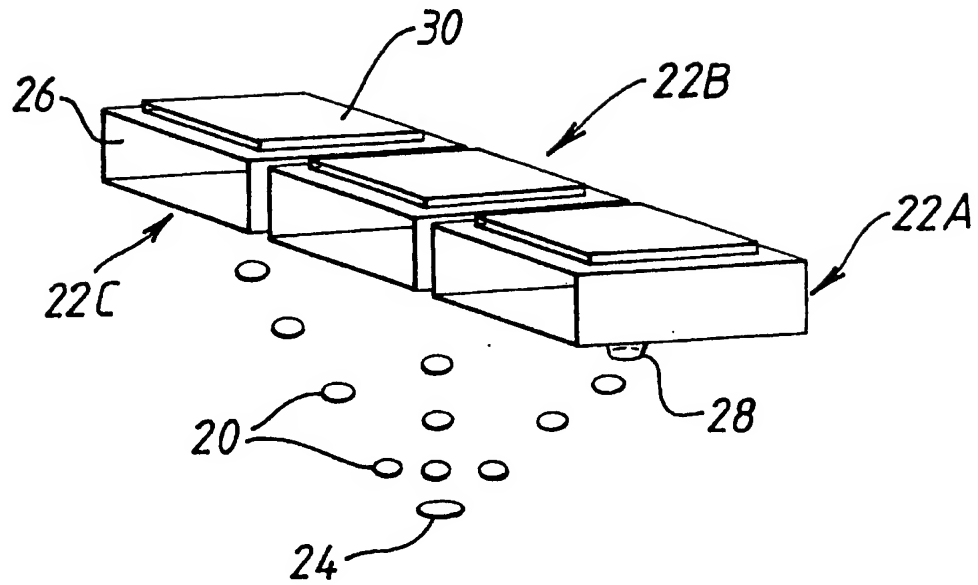
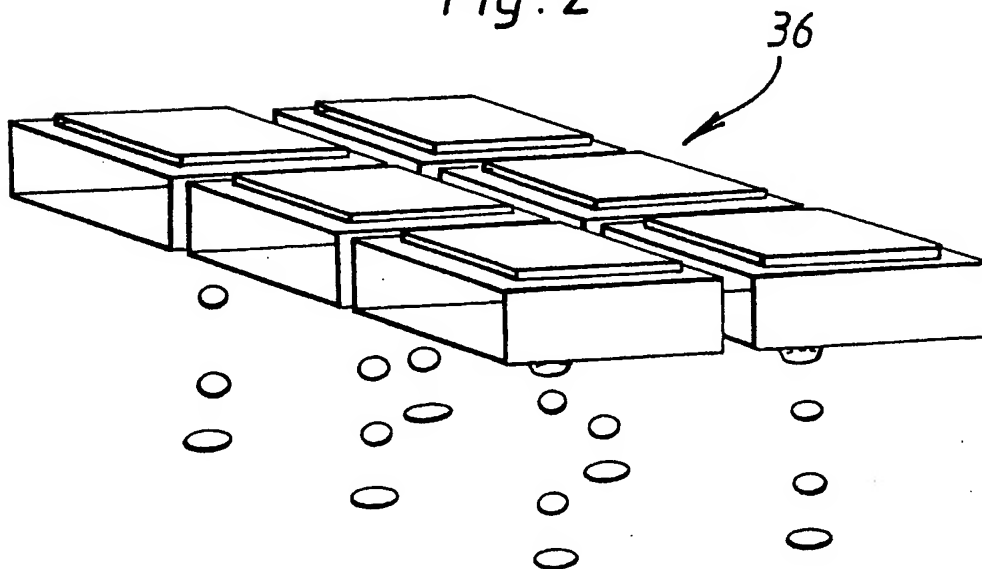


Fig. 2



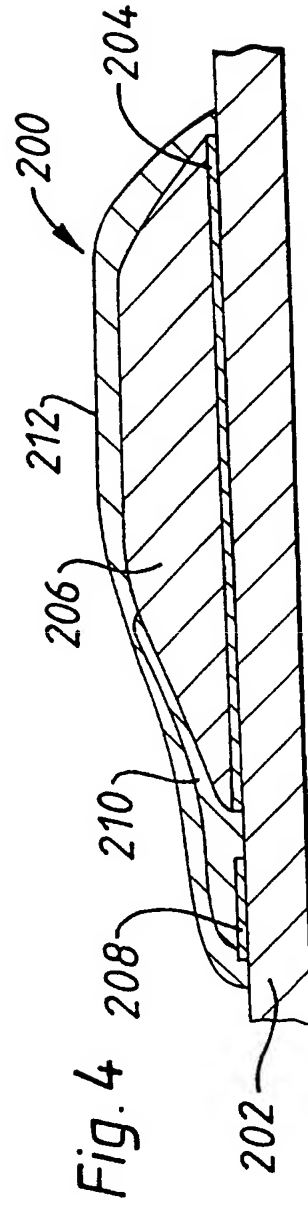
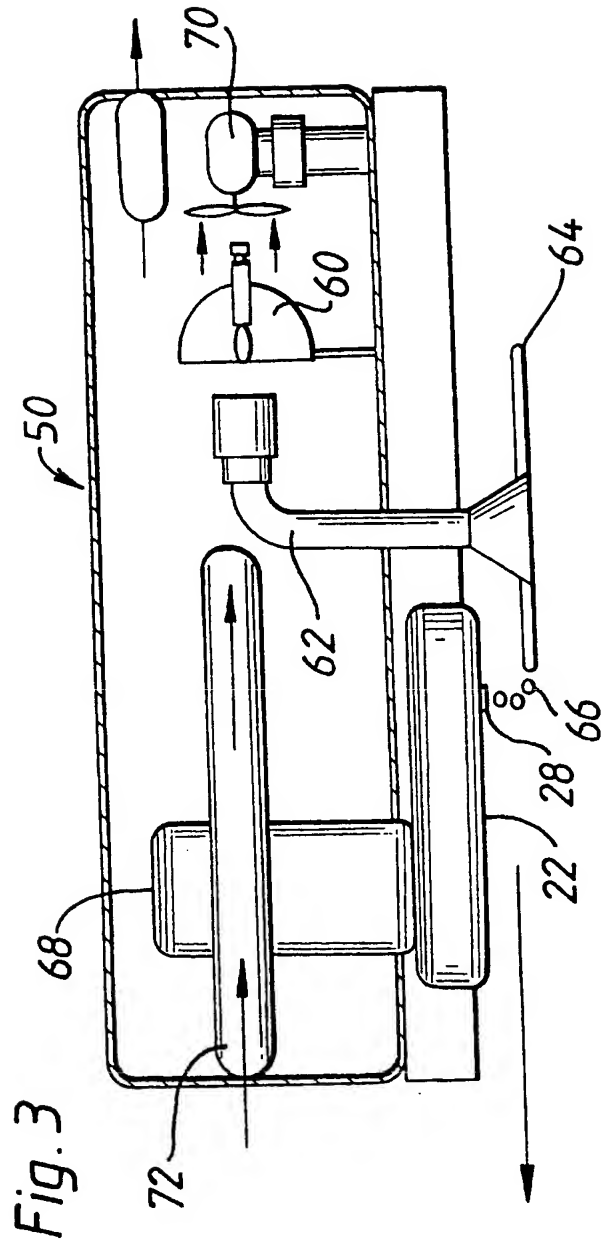
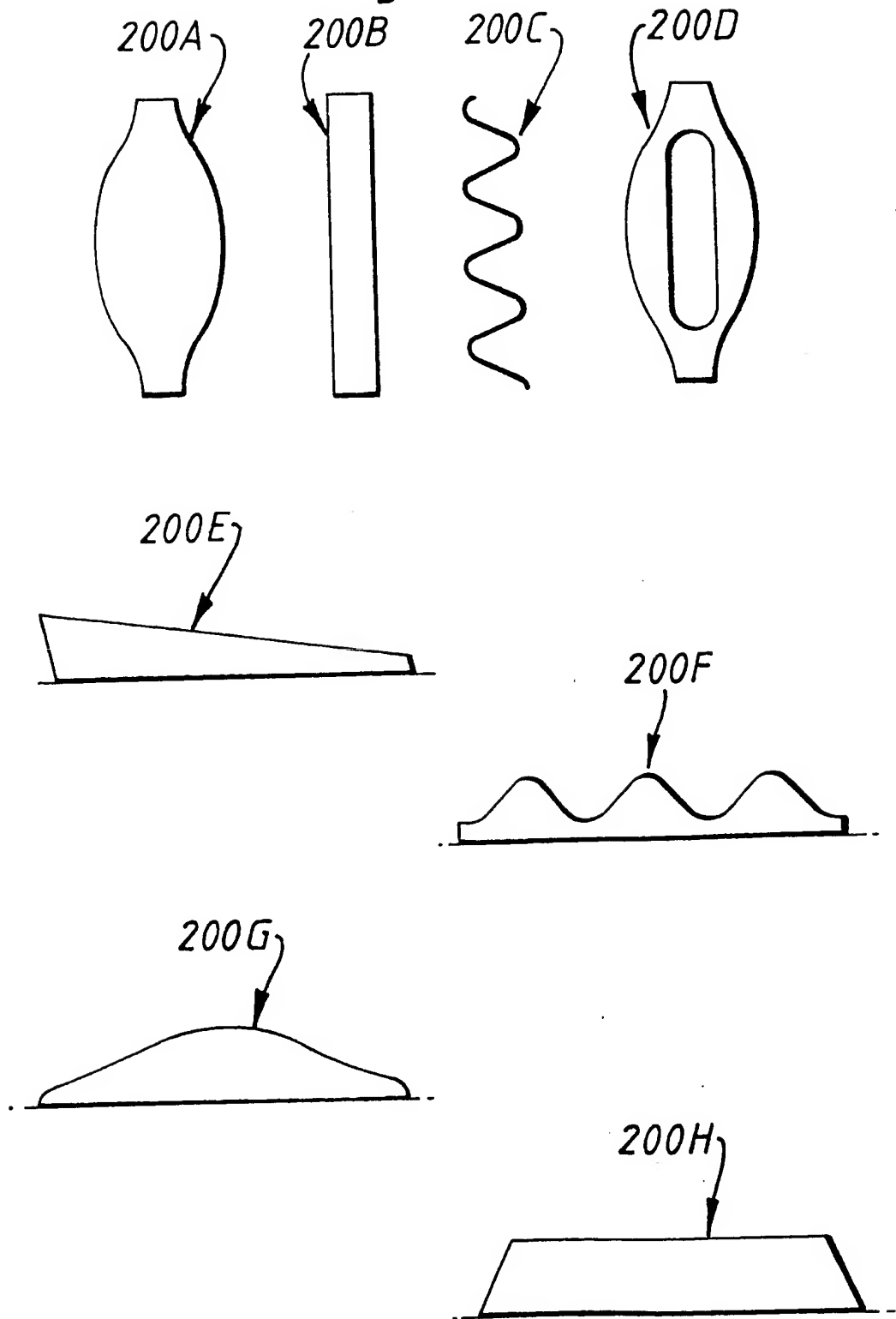
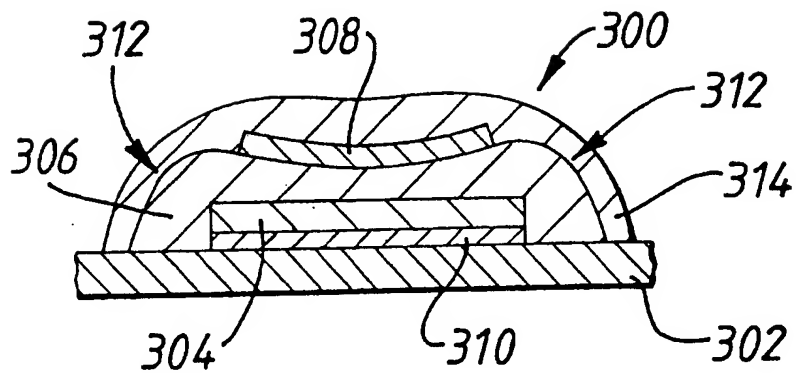


Fig. 5



*Fig. 6*



*Fig. 7(a)*

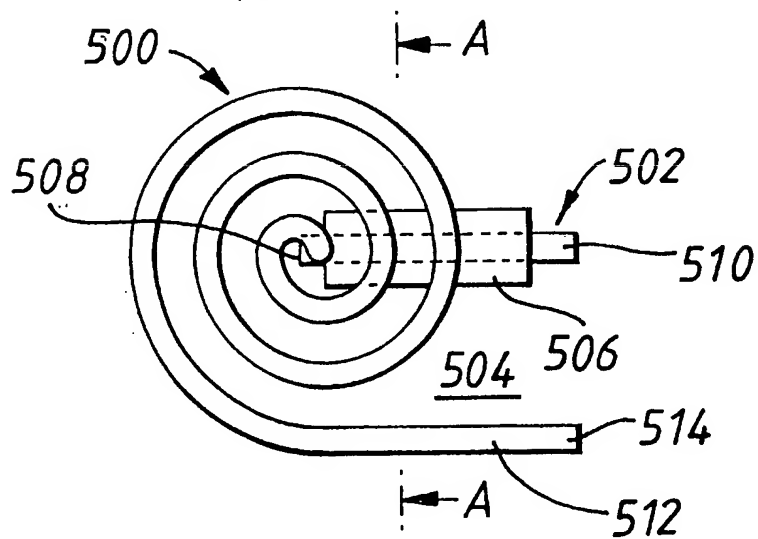
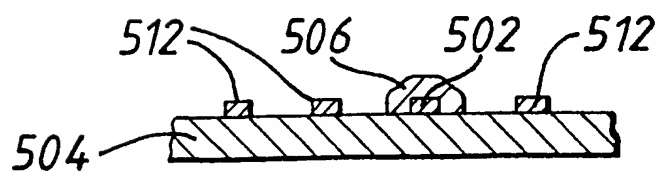


Fig. 7(b)



**METHOD OF FORMING A CIRCUIT ELEMENT ON A SURFACE**

The present invention relates to a method for forming a circuit element, that is, a resistor, capacitor or inductor, on a surface.

5

In one aspect, the present invention addresses the problem of accurate and fast formation of a circuit element on a surface.

10

Drop-on-demand printing is a known printing technique whereby a droplet of ink is ejected from an inkjet printer head. The droplet impacts with a porous or semi-porous surface, dries and forms a spot which forms a recognisable pattern and colour such as type.

15

According to one aspect of the present invention there is provided a method of forming an electrical resistor on a surface using the technique of droplet ejection to deposit droplets of deposition material, the resistor being formed from polymeric material and including a layer for promoting adhesion between the polymeric material and the surface, said method comprising the steps of depositing said layer on said surface and depositing said polymeric material on said layer to form said resistor.

20

This aspect of the present invention extends to an electrical resistor formed on a surface using the technique of droplet ejection to deposit droplets of deposition material, said resistor being formed from deposited polymeric material and including a deposited layer for promoting adhesion between the polymeric material and the surface.

25

The present invention can make use of an ink-jet printhead to eject droplets of fluid that coalesce on a surface and when suitably dried form a three-dimensional feature. By using the technique of droplet ejection, a circuit element can be formed using a relatively fast process that requires no hard photolithographic masks for patterning. The process can be relatively efficient, in that material is deposited only where it is required in the finished product, that

30

is, there is no need to use any process for the removal of deposited material.

The volume of each droplet is typically between 1 picolitre and 1 microlitre. This enables the final shape of the circuit elements to be accurately controlled during the formation thereof, and enables a wide variety of different shapes of circuit elements to be formed.

The application of the invention is wide. For instance, flexible printed circuits can be fabricated using conductive print to provide contact to the selected element for electrical access and to provide a conductive route between circuit elements.

The polymeric material may comprise one of PTFE, PMMA and polyaniline containing a suitable electron injecting barrier material.

The droplets forming the polymeric material and the droplets forming the adhesion promoting layer may be supplied by respective droplet deposition printheads.

The droplets forming the polymeric material and the droplets forming the adhesion promoting layer may be supplied by a butted droplet deposition printhead having a plurality of separate fluid supplies.

The method may further comprise the step of subjecting the resistor to infra-red radiation to "reflow" the resistor in order to maximise the "void fraction" of the resistor. This can influence the resistance value of the resistor.

In a second aspect the present invention provides a method of forming an electrical capacitor on a surface using the technique of droplet ejection to deposit droplets of deposition material, the capacitor comprising a first polymeric conductive layer formed on said surface, a polymeric dielectric layer formed on said first conductive layer and a second polymeric conductive layer formed on said dielectric layer, said method comprising the steps of depositing said first polymeric conductive layer on said surface, depositing said polymeric dielectric



layer on said first conductive layer and depositing said second polymeric conductive layer on said dielectric layer.

5 This aspect of the invention extends to an electrical capacitor formed on a surface using the technique of droplet ejection to deposit droplets of deposition material, said capacitor being formed from a first polymeric conductive layer deposited on said surface, a polymeric dielectric layer deposited on said first conductive layer and a second polymeric conductive layer deposited on said dielectric layer.

10

The capacitor may further comprise a layer for promoting adhesion between said first conductive layer and said substrate, said method comprising depositing said layer on said substrate before deposition of said first conductive layer.

15 Opposing side edges of said dielectric layer may be locally thickened to eliminate electric field breakdown due to current bunching at the edges of the conductive layers.

20 The dielectric layer may be formed from one of siloxane and fluorinated polyimide.

The droplets forming respective layers may be supplied by respective droplet deposition printheads.

25 Alternatively, the droplets forming respective layers are supplied by a butted droplet deposition printhead having a plurality of separate fluid supplies.

30 The method may further comprise the step of isolating hermetically said circuit element by depositing an isolating layer on the surface thereof. The isolating layer may be formed from an ormocer.

In a third aspect the present invention provides a method of forming an electrical inductor on a surface using the technique of droplet ejection to deposit droplets

of deposition material, the inductor comprising a first polymeric conductive layer formed on said surface, an insulator layer formed on said first conductive layer and a second polymeric conductive layer, said method comprising the steps of depositing said first polymeric conductive layer on said surface, depositing said  
5 insulator layer on said first conductive layer so as to expose first and second contacts of the first conductive layer, and subsequently depositing said second polymeric conductive layer in the form of a spiral having a centre coincident with said first contact and an end substantially aligned with said second contact.

10 This aspect of the present invention extends to an electrical inductor formed on a surface using the technique of droplet ejection to deposit droplets of deposition material, the inductor being formed from a first polymeric conductive layer deposited on said surface, an insulator layer deposited on said first conductive  
15 layer so as to expose first and second contacts of the first conductive layer, and a second polymeric conductive layer deposited in the form of a spiral having a centre coincident with said first contact and an end substantially aligned with said second contact.

In another aspect, the present invention provides a method of forming a plurality  
20 of circuit elements on a surface using the technique of droplet ejection to deposit droplets of deposition material, said method comprising depositing a plurality of droplets to form a first circuit element, depositing a plurality of droplets to form an isolation layer on said first circuit element and depositing a plurality of droplets on said isolation layer to form a second circuit element, wherein each  
25 of the circuit elements comprises one of an electrical resistor as aforementioned, an electrical capacitor as aforementioned, and an electrical inductor as aforementioned.

This enables, for example, complete LCR circuits to be formed using the  
30 technique of droplet deposition.

An important consequence of the ability to print multiple-level conductive elements, termed "cross-over conductors", is that the region of cross-over can

be used to form an circuit element, such as a resistor or a capacitor. The properties of the material sandwiched between the conductive elements may be dependent upon the dielectric properties of the droplets which have impacted and cured on the upper surface of the bottom-most conducting element.

5

Printing materials may include, but are not restricted to:

- conductive and semi-conductive polymers, for example:
  - co-polyaniline;
  - polyacetylene derivative;
  - 10 poly(para-phenylene);
  - polythiophene;
  - inorganic polymers; and
  - particulates including, for example, gold, nickel coated polystyrene and graphite;
- 15 • polymer blends and mixtures;
- organically modified ceramics ("ormocers");
- organically modified silicates ("ormosils");
- sol-gels; and
- cermets.

20

Thus, the present invention can use low or zero toxicology-rated fluids.

The viscosity range is preferably less than or equal to 100 centipoise (cps), based on 100% solid and dilute systems. The surface energy of such fluids may  
25 be in the range from 15 to 75 dynes.cm<sup>-1</sup>. Consequently, a low surface energy nozzle or a controlled wetting nozzle annulus may be required to minimise surface wetting and the concomitant drive voltage required to expel a droplet from the nozzle.

30 The size of a circuit element may be determined by at least one of surface wetting, droplet volume, and solid content of the fluid to be ejected, as well as any shrinkage that may take place for different degrees of curing.

The substrate surface energy dictates the control over the fluid spreading, or wetting, assuming that the curing process is implemented after the fluid has wet the surface. Controlled coalescence of sequential, in-line drops can be achieved either by modifying the software-controlled index distance that the printhead  
5 travels between successive droplet release, or alternatively, or additionally, irradiating the surface with a suitable secondary energy source which influences the fluid wetting and surface transport by increasing the rate of drying so as to promote thixotropy and a significant change in rheology. This control permits the build-up of material independently in all three dimensions.

10

The method may further comprise the step of electrically isolating the surface before forming said circuit element thereon. This step may comprise depositing an adhesion-promoting layer on said surface.

15 The surface may be flexible. For example, the surface may comprise a flexible plastic, preferably polyethylene, sheet. The surface may be either planar or irregular.

20 The circuit elements can form an enabling step for the generic technology of printing circuits on to temperature-sensitive substrates, such as polyethylene flexible plastic sheet. Such circuits include, but are not limited to, filters, resonators, networks, transmission lines, digital circuits, modulators and signal conditioners.

25 Advantageously the method further comprises the step of subjecting the deposition material to radiation treatment before, during or after deposition. The print surface may be subjected to radiation to prepare it for the deposition material. Employing in-situ UV and infrared radiation exposure can provide considerable scope for modifying the reaction of the droplet in order to achieve  
30 the required feature and profile.

The present invention will now be described by way of illustration only and with reference to the accompanying Figures in which:

Figure 1 shows three deposition heads directed towards a coincident drop site on a print surface;

Figure 2 shows an array of deposition heads;

5

Figure 3 shows a cross-sectional view of a deposition head in combination with a UV light source;

Figure 4 shows a cross-sectional view of a resistor;

10

Figure 5 shows a selection of profiles for a resistor;

Figure 6 shows a cross-sectional view of a capacitor;

15 Figure 7a shows a schematic diagram of an inductor; and

Figure 7b shows a cross-section along line A-A in Figure 7a.

20 Referring to Figure 1 a three-dimensional circuit element is formed on a printing surface using a drop-on-demand deposition technique to drop multiple droplets of a deposition material from a number of deposition heads 22A, 22B, 22C. The deposition heads have a height above the printing surface between 5 $\mu$ m and 1000 $\mu$ m. Each deposition head 22A, 22B, 22C holds the deposition material and ejects it a droplet at a time on demand onto the print surface. The  
25 deposition materials comprise in excess of 0.01% solid matter and may be any one of the materials discussed in the introduction.

Each deposition head comprises a pressure generation cavity 26 with a profiled cylindrical nozzle 28 in one wall of the cavity and a PZT bimorph actuator 30 in  
30 an opposite wall. Each nozzle 28 defines a line of ejection which is representative of the path a droplet of deposition material will take upon ejection.

Figure 1 shows three deposition heads directed towards a single drop site,

although any suitable number of deposition heads may be used to form the desired circuit element. Of course, each deposition head may be directed towards respective drop sites rather like a conventional printer head, as shown in Figure 2. Such a two-dimensional array 36 may provide for the simultaneous  
5 deposition of multiple droplets.

Figure 3 shows a deposition head 22 as part of a X-Y deposition system 50. The system 50 includes a quartz-halogen lamp 60 supplying UV light through an optical fibre 62 to the printing surface 64 onto which the droplets 66 are  
10 deposited. This system 50 subjects the deposition material to radiation treatment after it has been deposited for the purposes of curing the material or other processing.

The system 50 employs digital deposition servo drive motors for x-axis and y-  
15 axis transport motion. A replaceable polymer deposition head 22, along with its associated polymer reservoir cartridge(s) 68, resides on the axis drive carriage plate. Integrated into the carriage plate is a set of annular fibres that permit close proximity UV and infrared radiation for surface pre-treatment, in-flight treatment and/or post deposition treatment. The annular radiation emitters are  
20 fed from a fibre optic 62 that is coupled at the opposite end to the light source 60. The deposition surface 64 may be electrostatically secured to the deposition frame. The use of a cooling fan 70 and cooling air directional ducting 72 maintains the system 50 at a working temperature.

25 The characteristics of the element to be produced are drawn on a computer screen using a suitable draw facility software package or are imported into the plotter drive computer memory using a digital scanning facility (with on board character recognition capability, as required). The finished map is digitised and the appropriate x-y co-ordinates are fed to the system interface so that the  
30 required element is formed at the location requested. The drive waveform to the droplet dispense pressure generator (polymer dispense head) is synchronised to the x-y placement co-ordinates, so that the required element is accurately placed. For specific surfaces it is possible to employ an adhesion enhancing

liquid pre-treatment prior to depositing the required polymeric pattern.

Integral continuous or pulsed UV (also in conjunction with infrared radiation - thermally assisted curing) light source with illumination of the dispensing droplet  
5 via a fibre-optically fed focusing annulus may be located in close proximity to the dispensing head (or nozzle array). Note that in the limit (high value or high polymer dispense volume applications) this light source could be an excimer laser that employs a rotating mirror arrangement to create a fine line UV light beam that is continuously rotating around a selectable circular radius or more  
10 complex elliptical shape. The annulus can be formed by using a suitable retaining mould in the Y-spider plate, and with the use of a pre-shaped top casting cap, PMMA or alternative polymer can be injected into the unit for a UV transmitting annulus with a particular optical focusing. It is envisaged that a suitable light source can be manufactured that would enable the annulus to be  
15 fed from a source that is also integrated onto the y-axis carriage plate.

The shape and surface of the nozzle 28 determines the energy needed to eject the droplet from the nozzle. A polished nozzle 28 will have a lower surface energy than an unpolished nozzle and therefore will more easily release a  
20 droplet. A low surface energy nozzle exit can be achieved using a variety of liquid coatings (i.e Montedison Galydene), however a more practical route is to gravure print a silicone loaded acrylic UV curing film on to the front of the nozzle plate (this exhibits a surface energy of less than or equal to 19 dyn cm (190µjoules) ). One advantage of using such coating materials is that the nozzle  
25 can be made of both copper (wetting) and laminate material (wetting or non-wetting) giving more flexible control over the direction of droplet ejection. Both materials can be obtained in a variety of metal and laminate core thicknesses.

The nozzle may incorporate an integral piezoelectric bimorph nozzle shutter (not  
30 shown) to act as a sealant for the deposition material retained in the nozzle. This feature prevents ultraviolet light and water vapour from entering the nozzle when not in use. The shutter may comprise a plunger retained in the deposition chamber of the deposition head. Such a plunger means has a relative coaxial

sliding fit with the nozzle whereby a plunger head aligns with the nozzle aperture to close the nozzle and in an open position the plunger is retracted into the chamber. By controlling the position of the plunger head with respect to the nozzle aperture, the deposition chamber size can be controlled thereby allowing  
5 an adjustable droplet of deposition material to be ejected.

The nozzle may comprise means for directly varying the size of the nozzle aperture whereby the means is an iris type arrangement.

10 A deposition control electric field generator may be used to generate an electric field in the vicinity of the nozzle to control the shape of a meniscus of the electrically responsive deposit materials. This is used to exert a pulling force on the droplets so that less energy is required by the actuators to eject the droplets from the nozzle chamber.

15 Material may be dispensed in a vacuum to facilitate the deposition of droplets of diameter substantially less than or equal to  $1\mu\text{m}$ . If this were attempted in air then the drag induced by air resistance would distort the droplet and impair its dimensional stability and placement accuracy.

20 Examples of circuit elements according to the present invention which may be formed using the technique of droplet ejection will now be described with reference to Figures 4 to 7.

25 Figure 4 is a cross-section of a polymeric resistor 200 formed on surface 202. The resistor 200 comprises an adhesion promoting layer 204 and controlled-resistance polymer 206 formed on the layer 204. The resistor 200 is connected to a conductive track 208 formed on the surface 202 by a polymeric electrical contact 210. An isolating layer 212 is formed over the entire surface of the  
30 resistor and the conductive track.

Variation in the height  $d$ , width  $w$  and length  $L$  of the resistor 200, that is, the volume of the resistor 200, controls the specific resistance value  $R$  of the resistor



200 according to the equation:

$$R = \frac{\rho \cdot L}{w \cdot d}$$

5 where rho is the resistivity of the resistance polymer 206. Of course, the solid content per droplet will influence the resistivity of the polymer 206.

10 The resistor 200 may take any three-dimensional shape as determined by the designer of the resistor in view of the intended purpose of the resistor. Figure 5 shows top views of resistors 200A to 200D, and side views of resistors 200E to 200H. In addition, both of these profiles may be changed by sectioning the resistor following formation.

15 Electron and hole barrier reducing layers/interface doping can be used to enhance the functionality and stability of the resistor.

Figure 6 is a cross-section of a polymeric capacitor 300 formed on surface 302. The capacitor 300 comprises a first polymeric conductive layer 304, a polymeric dielectric layer 306 and a second polymeric conductive layer 308. The first conductive layer 304 may be deposited on an adhesion promoting layer 310; however, depending on the nature of the surface 302, this adhesion promoting layer may not always be necessary. As shown in Figure 6, the edges 312 of the dielectric layer 306 are locally thickened in order to eliminate the electric field breakdown due to current bunching at the edges of the conductive layers. An isolating layer 314 is formed over the entire surface of the capacitor 300.

25 Similar to the resistor, the capacitor can take any shape as determined by the designer of the capacitor in view of the intended purpose of the capacitor. For example, the dielectric layer 306 may comprise a plurality of layers of different material aligned either substantially parallel to or substantially perpendicular to  
30 the conductive layers 304 and 308.

Figures 7a and 7b shows schematic diagrams of an inductor 500 formed using a droplet deposition technique. The inductor 500 comprises a first polymeric conductive layer 502 formed on surface 504. An insulator layer 506 is then deposited over the conductive layer 502 so as to expose contacts 508 and 510 of the conductive layer 502. A second polymeric conductive layer 512 is subsequently deposited in the form of a spiral having a centre coincident with contact 510 and an end 514 substantially aligned with the contact 512. The size of the inductance of the inductor is determined by the number of "turns" of the spiral 512 and the material from which the insulator layer is formed.

10

It will be understood that the present invention has been described above purely by way of example, and modifications of detail can be made within the scope of the invention.

**CLAIMS**

1. A method of forming an electrical resistor on a surface using the technique of droplet ejection to deposit droplets of deposition material, the resistor being formed from polymeric material and including a layer for promoting adhesion between the polymeric material and the surface, said method comprising the steps of depositing said layer on said surface and depositing said polymeric material on said layer to form said resistor.
2. A method according to Claim 1, wherein the droplets forming the polymeric material and the droplets forming the adhesion promoting layer are supplied by respective droplet deposition printheads.
3. A method according to Claim 1, wherein the droplets forming the polymeric material and the droplets forming the adhesion promoting layer are supplied by a butted droplet deposition printhead having a plurality of separate fluid supplies.
4. A method according to any of Claims 1 to 3, wherein said polymeric material comprises one of polytetrafluoroethylene (PTFE), polymethyl methacrylate (PMMA) and polyaniline containing an electron injecting barrier material.
5. A method of forming an electrical capacitor on a surface using the technique of droplet ejection to deposit droplets of deposition material, the capacitor comprising a first polymeric conductive layer formed on said surface, a polymeric dielectric layer formed on said first conductive layer and a second polymeric conductive layer formed on said dielectric layer, said method comprising the steps of depositing said first polymeric conductive layer on said surface, depositing said polymeric dielectric layer on said first conductive layer and depositing said second polymeric conductive layer on said dielectric layer.

6. A method according to Claim 5, wherein said capacitor further comprises a layer for promoting adhesion between said first conductive layer and said substrate, said method comprising depositing said layer on said substrate before deposition of said first conductive layer.
- 5
7. A method according to Claim 5 or 6, wherein opposing side edges of said dielectric layer are locally thickened to eliminate electric field breakdown due to current bunching at the edges of the conductive layers.
- 10
8. A method according to any of Claims 5 to 7, wherein the dielectric layer is formed from one of siloxane and fluorinated polyimide.
9. A method according to any of Claims 5 to 8, wherein the droplets forming respective layers are supplied by respective droplet deposition printheads.
- 15
10. A method according to any of Claims 5 to 8, wherein the droplets forming respective layers are supplied by a butted droplet deposition printhead having a plurality of separate fluid supplies.
- 20
11. A method according to any preceding claim, further comprising the step of depositing an isolating layer over the surface of said resistor or capacitor.
12. A method of forming an electrical inductor on a surface using the technique of droplet ejection to deposit droplets of deposition material, the inductor comprising a first polymeric conductive layer formed on said surface, an insulator layer formed on said first conductive layer and a second polymeric conductive layer, said method comprising the steps of depositing said first polymeric conductive layer on said surface, depositing said insulator layer on said first conductive layer so as to expose first and second contacts of the first conductive layer, and subsequently depositing said second polymeric conductive layer in the form of a spiral having a centre coincident with said first contact and an end substantially aligned with said second contact.
- 25
- 30

13. A method according to any preceding claim, wherein the droplet viscosity range is less than or equal to 100 centipoise.
14. A method according to any preceding claim, wherein the surface is flexible.  
5
15. A method according to Claim 14, wherein the surface comprises a plastic sheet.
- 10 16. A method according to any preceding claim, further comprising the step of subjecting the deposition material to radiation treatment before, during or after deposition.
- 15 17. A method according to any preceding claim, wherein the surface is subjected to radiation to prepare it for the deposition material.
- 20 18. An electrical resistor formed on a surface using the technique of droplet ejection to deposit droplets of deposition material, said resistor being formed from deposited polymeric material and including a deposited layer for promoting adhesion between the polymeric material and the surface.
- 25 19. An electrical resistor according to Claim 18, wherein said polymeric material comprises one of polytetrafluoroethylene (PTFE), polymethyl methacrylate (PMMA) and polyaniline containing an electron injecting barrier material.
20. An electrical resistor according to Claim 18 or 19, comprising an isolating layer deposited over the surface thereof.
- 30 21. An electrical capacitor formed on a surface using the technique of droplet ejection to deposit droplets of deposition material, said capacitor being formed from a first polymeric conductive layer deposited on said surface, a polymeric dielectric layer deposited on said first conductive layer and a second polymeric

conductive layer deposited on said dielectric layer.

22. An electrical capacitor according to Claim 21, comprising a layer deposited on said surface for promoting adhesion between said first conductive layer and said substrate.

23. An electrical capacitor according to Claim 21 or 22, comprising an isolating layer deposited over the surface thereof.

24. An electrical capacitor according to any of Claims 21 to 23, wherein the dielectric later is formed from one of siloxane and fluorinated polyimide.

25. An electrical capacitor according to any of Claims 21 to 24, wherein opposing side edges of said dielectric layer are locally thickened to eliminate electric field breakdown due to current bunching at the edges of the conductive layers.

26. An electrical inductor formed on a surface using the technique of droplet ejection to deposit droplets of deposition material, the inductor being formed from a first polymeric conductive layer deposited on said surface, an insulator layer deposited on said first conductive layer so as to expose first and second contacts of the first conductive layer, and a second polymeric conductive layer deposited in the form of a spiral having a centre coincident with said first contact and an end substantially aligned with said second contact.

27. A method of forming a plurality of circuit elements on a surface using the technique of droplet ejection to deposit droplets of deposition material, said method comprising depositing a plurality of droplets to form a first circuit element, depositing a plurality of droplets to form an isolation layer on said resistor, and depositing a plurality of droplets on said isolation layer to form a second circuit element, wherein each of said circuit elements comprises one of an electrical resistor according to any of Claims 18 to 20, an electrical capacitor according to any of Claims 21 to 25 and an electrical inductor according to Claim

26.

28. A method of forming an electrical resistor or an electrical resistor  
substantially as herein described with reference to Figure 4 of the accompanying  
5 drawings.

29. A method of forming an electrical capacitor or an electrical capacitor  
substantially as herein described with reference to Figure 6 of the accompanying  
drawings.

10

30. A method of forming an electrical inductor or an electrical inductor  
substantially as herein described with reference to Figures 7a and 7b of the  
accompanying drawings.